Tornadoes

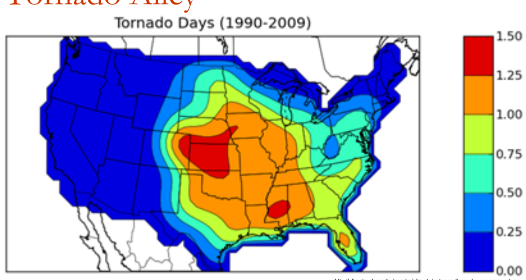
Photo: D. Zaras, NOAA

Dr. Christopher M. Godfrey
University of North Carolina at Asheville

Tornadoes

- A tornado is a violently rotating column of air in contact with the ground
- *Tornadogenesis* is the formation of a tornado
- A visible condensation funnel is NOT necessary to have a tornado
- However, just a funnel without a circulation in contact with the ground is NOT a tornado
- Tornadoes may have wind speeds between 40 and 300+ m.p.h!
- On a local scale, the tornado is the most intense of all atmospheric circulations

Tornado Alley



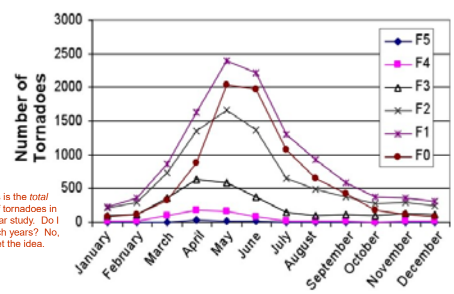
http://climate.ok.gov/index.php/climate/category/tornadoes_severe_storms

- 75% of all tornadoes occur in the U.S.
- Most tornadoes occur in tornado alley (central Texas to Nebraska)

When do tornadoes occur?

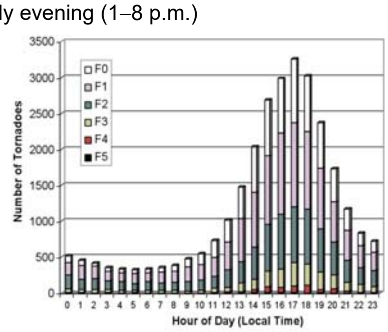
- Mainly during spring (April, May, June) in the U.S.
- Tornadoes can occur year-round!

Note: This is the *total* number of tornadoes in a multi-year study. Do I know which years? No, but you get the idea.



Tornado Frequency by Time of Day

- Most tornadoes occur from late afternoon through early evening (1–8 p.m.)



The Fujita Scale (Used prior to 2007)

- Relates tornado intensity indirectly to structural and/or vegetative *damage*

Scale	Wind Speed (KPH)	Wind Speed (MPH)	Expected Damage
F0	<116	<72	**Light Damage** Damage to chimneys and billboards; broken branches; shallow-rooted trees pushed over.
F1	116–180	72–112	**Moderate Damage** The lower limit is near the beginning of hurricane wind speed. Surfaces peeled off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off the road.
F2	181–253	113–157	**Considerable Damage** Roofs torn off frame houses; mobile homes demolished; boxcars pushed over; large trees snapped or uprooted; light-object missiles generated.
F3	254–332	158–206	**Severe Damage** Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off ground and thrown.
F4	333–419	207–260	**Devastating Damage** Well-constructed houses leveled; structures with weak foundations blown some distance; cars thrown and large missiles generated.
F5	>419	>260	**Incredible Damage** Strong frame houses lifted off foundations and carried considerable distance to disintegrate; automobile-sized missiles fly through the air farther than 100 m; trees debarked; incredible phenomena occur.

Tornado Damage

The Enhanced Fujita Scale

- EF-Scale in use by the NWS starting February 1, 2007
- More complex than F-Scale

Photo: Jim LaDue

Why the NWS created the EF-Scale

- Need more damage indicators
- To recalibrate winds associated with F-scale ratings
- To better correlate wind and rating
- To account for construction variability
- Flexibility, extensibility, expandability

The framed house is one of only a few F-scale damage indicators.

Evidence indicates that a well-constructed house can be blown away by winds much less than 260 m.p.h. (F5 threshold).

EF-Scale Damage Indicators (DIs)

- 28 DIs identified initially
- Each DI has several Degrees of Damage (DOD)
- DIs and DODs can be added or modified

28 Damage Indicators

Table 3.

Damage Indicators for EF Scale

DI No.	Damage indicator (DI)
1	Small Barns or Farm Outbuildings (SBO)
2	One- or Two-Family Residences (FR12)
3	Manufactured Home – Single Wide (MHSW)
4	Manufactured Home – Double Wide (MHDW)
5	Apartments, Condos, Townhouses [3 stories or less] (ACT)
6	Motel (M)
7	Masonry Apartment or Motel Building (MAM)
8	Small Retail Building [Fast Food Restaurants] (SRB)
9	Small Professional Building [Doctor's Office, Branch Banks] (SPB)
10	Strip Mall (SM)
11	Large Shopping Mall (LSM)
12	Large, Isolated Retail Building [K-Mart, Wal-Mart] (LIRB)
13	Automobile Showroom (ASR)
14	Automobile Service Building (ASB)
15	Elementary School [Single Story; Interior or Exterior Hallways] (ES)
16	Junior or Senior High School (JHSH)
17	Low-Rise Building [1-4 Stories] (LRB)
18	Mid-Rise Building [5-20 Stories] (MRB)
19	High-Rise Building [More than 20 Stories] (HRB)
20	Institutional Building [Hospital, Government or University Building] (IB)
21	Metal Building System (MBS)
22	Service Station Canopy (SSC)
23	Warehouse Building [Tilt-up Walls or Heavy-Timber Construction] (WHB)
24	Transmission Line Towers (TLT)
25	Free-Standing Towers (FST)
26	Free-Standing Light Poles, Luminary Poles, Flag Poles (FSP)
27	Trees: Hardwood (TH)
28	Trees: Softwood (TS)

Residences

Commercial/retail structures

Schools

Professional buildings

Metal buildings/canopies

Towers/poles

Vegetation

Degrees of Damage

Some consecutive DODs have larger overlap than others

DOD	Damage Description	EXP	LB	UB
1	Threshold of visible damage	63	53	80
2	Loss of roof covering material (<20%), gutters and/or awning; loss of vinyl or metal siding	79	63	97
3	Broken glass in doors and windows	96	79	114
4	Uplift of roof deck and loss of significant roof covering material (>20%); collapse of chimney; garage doors collapse inward or outward; failure of porch or carport	97	81	116
5	Entire house shifts off foundation	121	103	141
6	Large sections of roof structure removed; most walls remain standing	122	104	142
7	exterior walls collapsed	132	113	153
8	Most walls collapsed except small interior rooms.	152	127	178
9	All walls collapsed	170	142	198
10	Destruction of engineered and/or well constructed residence; slab swept clean	200	162	220

Expected, Lower Bound, and Upper Bound of wind speed (in m.p.h.) for each Degree of Damage

F-Scale Converted to EF-Scale

F Scale	Wind Speed	EF-Scale	Wind Speed
F0	45-78	EF0	65-85
F1	79-117	EF1	86-109
F2	118-161	EF2	110-137
F3	162-209	EF3	138-167
F4	210-261	EF4	168-199
F5	262-317	EF5	200-234

DOD to Wind Speed to EF-Scale question

DOD	Damage Description – Framed House	EXP	LB	UB
1	Threshold of visible damage	63	53	80
2	Loss of roof covering material (<20%), gutters and/or awning; loss of vinyl or metal siding	79	63	97
3	Broken glass in doors and windows	96	79	114
4	Uplift of roof collapse of c porch or carp	97	81	116
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Expected wind:
97 mph

EF-Scale answer

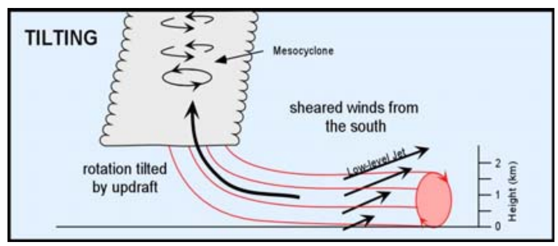
EF-Scale Categories	Wind Speed Ranges
EF0	65-85
EF1	86-110
EF2	111-135
EF3	136-165
EF4	166-200
EF5	>200

Wind Speed in mph, 3-Second gust

Tornado Formation

Tilting

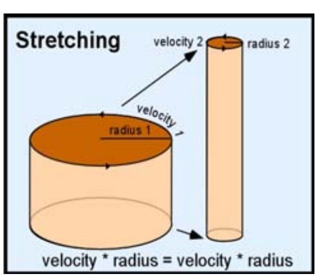
- Vertical wind shear gets tilted horizontally to form the rotating mesocyclone



Tornado Formation

Vortex stretching

- RFD cuts off warm air source from low-level updraft circulation → rises more slowly
- Upper-level updraft stretches the entire circulation
- Tornado forms by conservation of angular momentum



Let's use some math to see how this works…

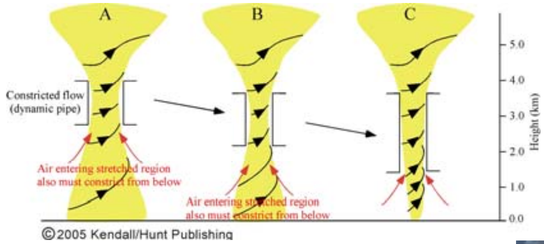
Tornado Formation

Vortex stretching

Tornado Formation

Dynamic pipe effect

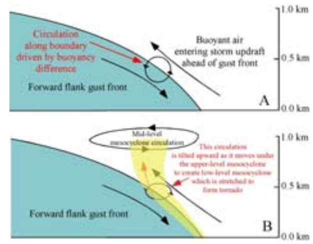
- Constricted mid-level flow in stretched portion of vortex forces lower levels to constrict as well
- Process proceeds toward the ground



Tornado Formation

Bottom-up process

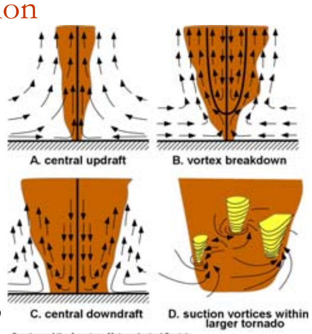
- Descending air behind gust front and ascending air ahead of gust front creates rotation
- As gust front moves under updraft, low-level mesocyclone rotation stretches beneath mid-level mesocyclone to form a tornado



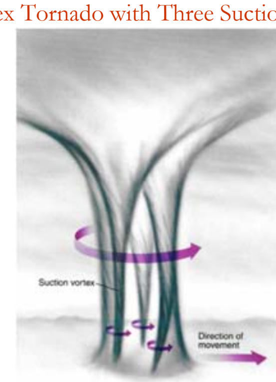
Tornado Formation

Vortex breakdown

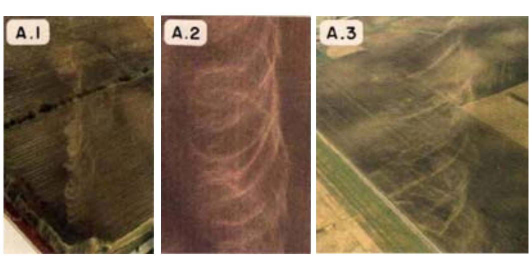
- Downdraft descends in central core of existing tornado
- Strong shear between updraft and central downdraft leads to smaller *suction vortices*
- Worst damage occurs from suction vortices
- The same process occurs in a *multiple vortex tornado*



Multi-Vortex Tornado with Three Suction Vortices



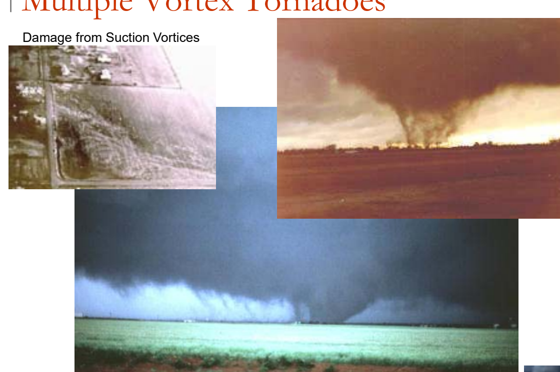
Examples of ground marks left behind by suction vortices within tornadoes



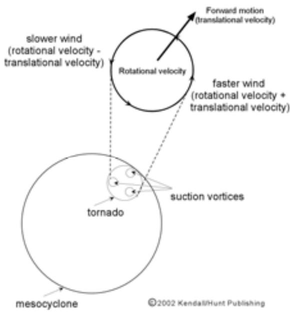
Source: Lewellen and Zimmerman, 2009: Bulletin of the American Meteorological Society

Multiple Vortex Tornadoes

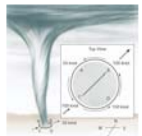
Damage from Suction Vortices



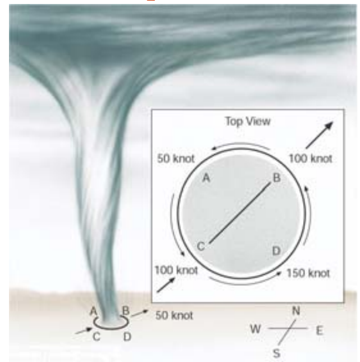
Tornado Wind Speeds



- Wind speeds depend on both rotational and translational velocities
- If a tornado travels east, then the strongest winds are on the southern edge of the tornado
- Suction vortices further increase or decrease resulting wind speed



Tornado Wind Speeds



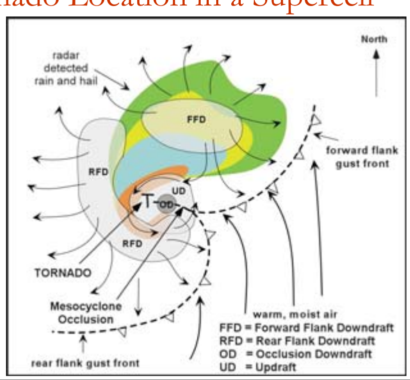
Features of a Tornadic Supercell

- Rotating updraft
- Hook echo (most of the time…)
- Rear flank downdraft (RFD)
- Mesocyclone
- Tornado
  - A tornado must exist at some point during the life of the supercell for it to be a 'tornadic' supercell

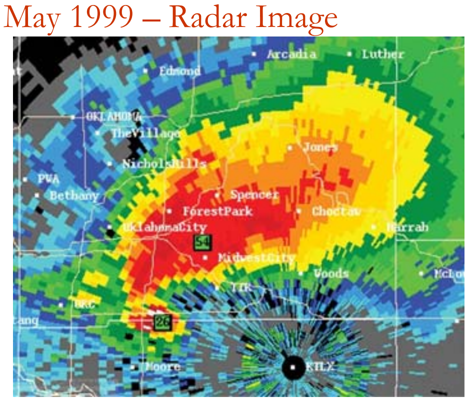
Rotating Updraft

- In *tornadic* supercells, the storms *usually* spin in only one direction (CCW)
- Because of the environmental shear that supercells form in, the updraft is enhanced on the southern flank of the storm
- The environment favors the CCW rotation typically found on the southern flank
- Rotation on the northern flank of the storm is usually weak

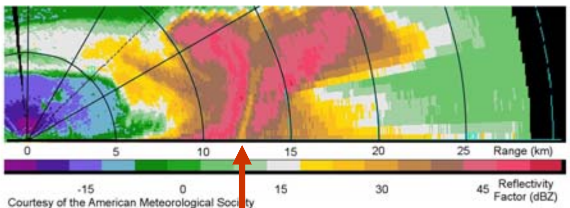
Tornado Location in a Supercell



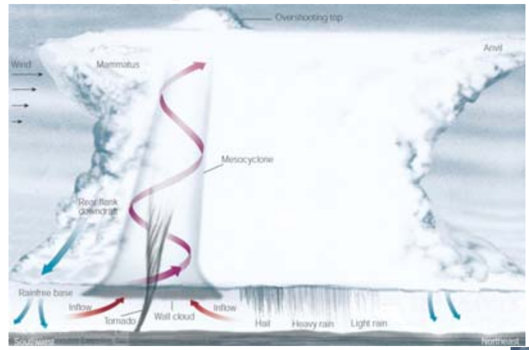
3 May 1999 – Radar Image



Radar Reflectivity – Vertical Scan of a Tornadic Supercell

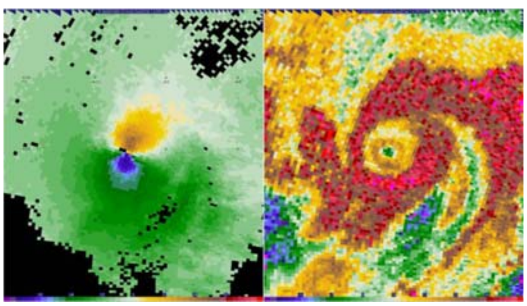


Tornadic Supercell



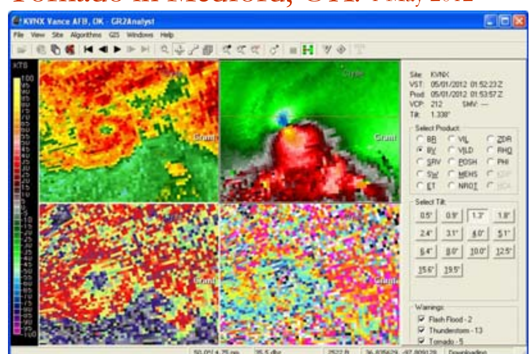
Rapid-Scan DOW Observations:

Goshen County, WY, 5 June 2009



Source: http://vortex2.org/dowloops/POSTERS-FINAL/RADARConf2011-RapidScan-FINAL-B.pdf

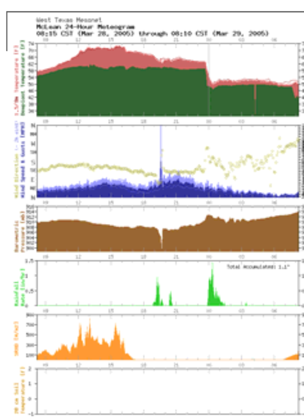
Tornado in Medford, OK: 1 May 2012



Forecasting Tornadoes

- Impossible to predict exact location of a tornado (so far…)
- No operational forecast models resolve tornadoes
- Examine specific indices from forecast models to determine locations favorable for supercell development
- SPC does this every day
  - 5 times a day for today
  - 2 times a day for tomorrow
  - 1 time a day for two days from now

Storm Prediction Center
Norman, Oklahoma



Tornado passage near McLean, Texas Mesonet site on 28 March 2007 (yes, 2007, despite the date in the image…)

Peak Gust: 127 m.p.h.
Pressure Drop: 9 mb

Other Small-Scale Vortices

- Landspout – a non-supercell tornado that forms without a preexisting midlevel mesocyclone; source of circulation is near the ground
- Gustnado – circulation spins up on leading edge of gust front

Photo: C. Godfrey

Waterspout

Dark-spot Stage

Mature or Spray-Vortex Stage

- Any tornado over water
- Usually a non-supercell tornado over water (develops over open water in fair weather)
- Life cycle:
  - dark-spot stage
  - spiral pattern stage
  - spray-ring stage
  - mature or spray-vortex stage
  - decay stage

Other Small-Scale Vortices

- Dust devil – A well-developed dust whirl, usually of short duration rendered visible by dust, sand, and debris
  - Can cause damage up to F1 on Fujita scale
  - Best developed on a hot, calm afternoon with clear skies, in a dry region where intense surface heating causes a very steep lapse rate

Tornado Myths

FAKE PICTURE! ←

Southwest Corner of Basement

- This myth dates back to 1887 in a book on tornadoes by John Park Finley.
- It reigned as popular wisdom for 80 years
- In 1966, a University of Kansas professor studied this question exactly – is the southwest corner safer?
- The answer was an emphatic NO!

Open Windows to Equalize Air Pressure

- It's a waste of time and puts *you* in the way of flying glass and debris
- It could actually help the wind to remove your roof and will allow debris into the house
- Inside/outside pressure differences would be equalized by fresh gaping holes in windows/doors/walls well before an explosive pressure drop could approach the house

Open Windows to Equalize Air Pressure

Rivers Protect Cities

- Dates back to Native American tribal legends
- Residents thought that Emporia, KS was "protected" by the Cottonwood and Neosho rivers. In 1974, a tornado killed six people and damaged $20 million worth of property. Another tornado struck Emporia in 1991.
- Tornadoes are so rare that one or two generations could pass without a tornado hitting a particular area

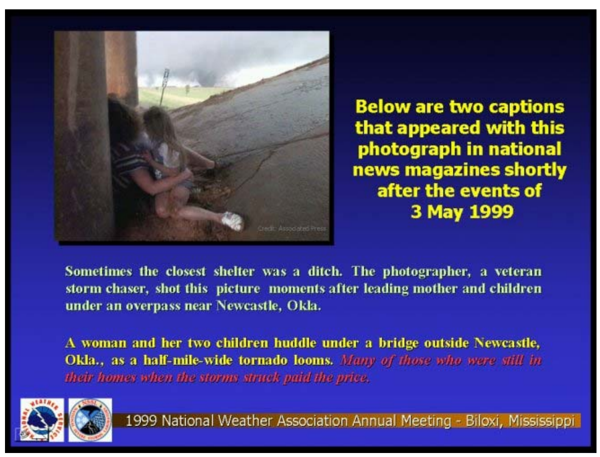
Hills Protect Cities

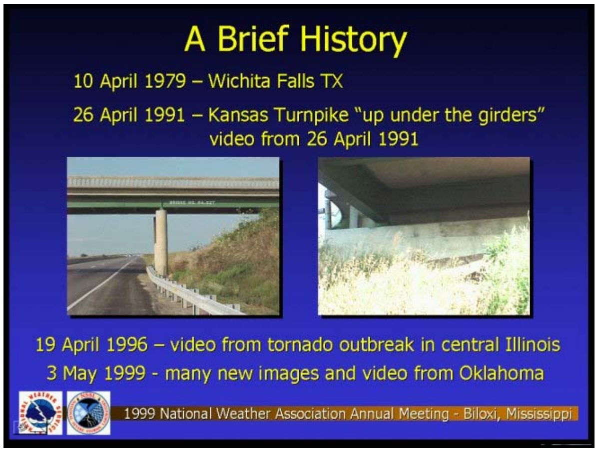
- Similar to the river-protection myth…
- Topeka was thought to be safe because of Burnett's Mound…until a tornado swept through town.
- Again, tornadoes are rare and small towns in the plains are mere needles in a haystack.

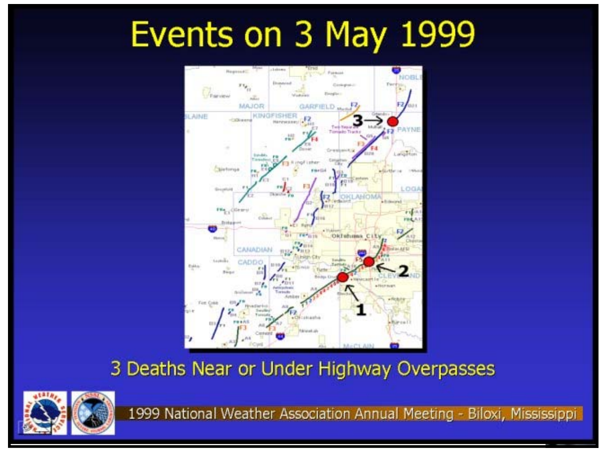
Tornadoes Never Strike Big Cities

Take Shelter Under an Overpass

- Modern day myth
- Dates back to 1991 and the Andover, KS tornado
- Film crew for TV station sought protection during a tornado from an overpass and the film was distributed widely
- The tornado was weak and *missed them!*
- Winds move *faster* under an overpass



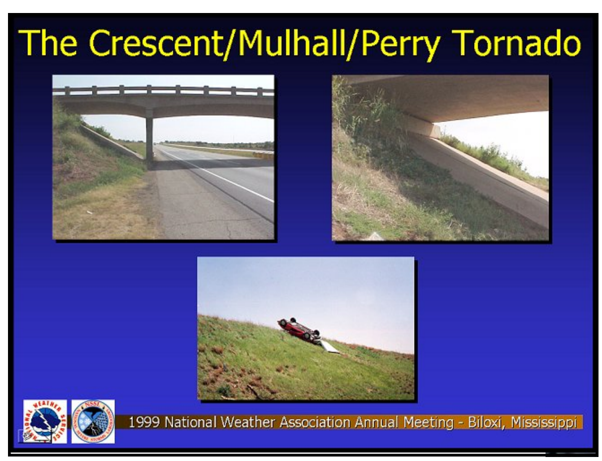

A Brief History
10 April 1979 – Wichita Falls TX
26 April 1991 – Kansas Turnpike "up under the girders" video from 26 April 1991
19 April 1996 – video from tornado outbreak in central Illinois
3 May 1999 - many new images and video from Oklahoma
1999 National Weather Association Annual Meeting - Biloxi, Mississippi

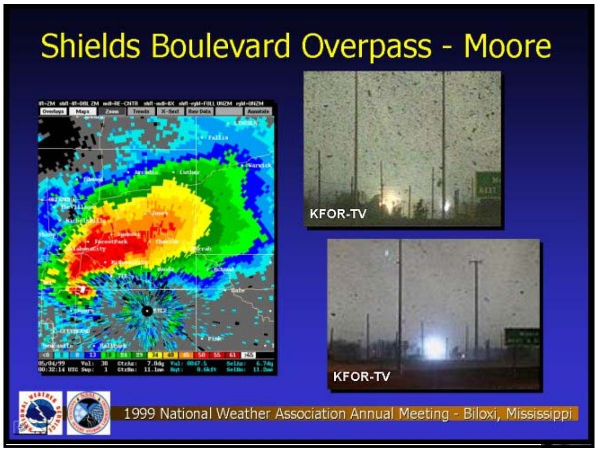

Events on 3 May 1999
3
2
1
3 Deaths Near or Under Highway Overpasses
1999 National Weather Association Annual Meeting - Biloxi, Mississippi

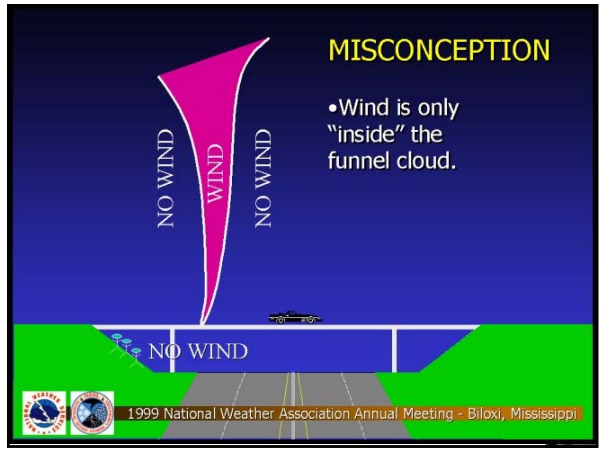

Highway Overpasses Are Inadequate Tornado Sheltering Areas
For the following meteorological reasons…
• Flying debris, missiles in airflow, debris collection
• Wind Channeling under Overpass
• Higher Wind Speeds above 'True' Ground Level
• Many (Most?) Overpasses have NO 'GIRDERS'
• Wind will change direction as vortex passes
This can be basically summarized as…
• Makes one a stationary target in an open area with virtually no protection
1999 National Weather Association Annual Meeting - Biloxi, Mississippi

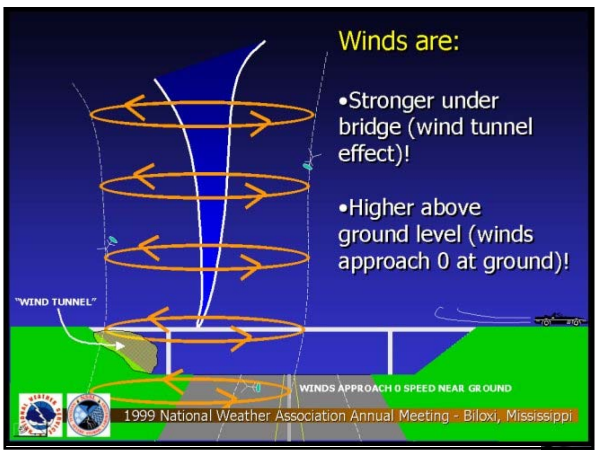

16th Street Overpass – Bridge Creek
1999 National Weather Association Annual Meeting - Biloxi, Mississippi


Shields Boulevard Overpass - Moore
1999 National Weather Association Annual Meeting - Biloxi, Mississippi


The Crescent/Mulhall/Perry Tornado
1999 National Weather Association Annual Meeting - Biloxi, Mississippi


Shields Boulevard Overpass - Moore
KFOR-TV
KFOR-TV
1999 National Weather Association Annual Meeting - Biloxi, Mississippi


MISCONCEPTION
•Wind is only "inside" the funnel cloud.
NO WIND
WIND
NO WIND
NO WIND
1999 National Weather Association Annual Meeting - Biloxi, Mississippi


Winds are:
•Stronger under bridge (wind tunnel effect)!
•Higher above ground level (winds approach 0 at ground)!
"WIND TUNNEL"
WINDS APPROACH 0 SPEED NEAR GROUND
1999 National Weather Association Annual Meeting - Biloxi, Mississippi